

The University of Chicago

VOLUME CHANGES IN ORGANS INDUCED
BY THE LOCAL APPLICATION OF
EXTERNAL HEAT AND COLD
AND BY DIATHERMY

A PART OF A DISSERTATION SUBMITTED TO
THE FACULTY OF THE DIVISION OF THE BIO-
LOGICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSIOLOGY

1931

By
SIMON BENSON

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ARCHIVES OF PHYSICAL THERAPY, X-RAY, RADIUM,
March, 1934, Vol. XV, pp. 133-148.



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VOLUME CHANGES IN ORGANS INDUCED BY THE LOCAL APPLICATION OF EXTERNAL HEAT AND COLD AND BY DIATHERMY *

SIMON BENSON, Ph.D.

CHICAGO

The work reported here was prompted by the results obtained in a previous investigation⁽²⁾ of certain thermic effects on joints stiffened by acute traumatic injuries. It was thought that there may be a relationship between the induced vascular and volume changes and the subsequent variations in motility, as shown by the previous work.

Methods

Volume changes following heat applications were determined by water displacement of the limb. The water into which a foot was submerged before application of heat, was usually at about 34° C., the average skin temperature; but for the measurement following heat application, the water temperature was raised to about 44° C., or close to the existing skin temperature, in order to prevent as much as possible, rapid reflex volume change during the measurement.

The measurements were taken by having the subject standing upright with one foot in a cylinder. The subject was instructed and trained to stand "exactly the same" during all measurements — i.e., the foot was placed as nearly as possible in the same place and position in a cylinder; that the back of the heel and the calf muscles just touched the cylinder wall, and with equal weight on both feet. With these precautions, the sensitivity of the apparatus (Fig. 1) yielded measurements of the foot and leg volume with a maximum error of 3 to 5 per cent. Average errors in all probability, do not exceed 5 cc. per test; and since errors are as likely to be (+) as (—), a large number of measurements will largely eliminate their influence, and may be ignored in the final averaged results.

We know of no method by which the treated limb may be replaced in the measuring vessel for a second measurement with greater accuracy. The arm or the leg cannot be re-

placed into the ordinary plethysmograph with any greater, if as great, accuracy as can a foot into a cylinder when the same body weight is brought to bear upon it during the measurements. The method is rapid as well. With but slight changes in the arrangement of indicators, etc., the device is applicable in all of our investigations, thus eliminating the introduction of new devices and new errors.

The subjects were almost all active athletes — apparently in the best of health. The results obtained can, therefore, be considered as reactions in normal men. It is true that as for the results of the first part of this report some of the measurements were obtained upon individuals with sprained ankles and other local acute injuries, such as bruises and contusions, but the majority were well on the road to recovery, there being little or no swelling left to introduce any noteworthy error in the results.

Hot water was applied to the subject standing with the foot submerged in whirling water; but in the diathermy tests, the subject was sitting with the foot placed upon a large electrode lying on the floor, and the other electrode placed as a cuff around the leg just below the knee. This we felt was the best arrangement of the electrodes to insure the most thorough application to all parts of the measured foot and leg. Hot air was applied with the subject sitting with the foot extended horizontally into the baker, with the part exposed to the heat always wrapped in toweling. The position of the subjects (standing, sitting) is emphasized here because of the possibility that a variation in the hydrostatic pressure of the blood in the foot and ankle might influence the change in volume — especially at temperatures at which the skin blood vessels undergo marked change in tone.

The volume-measuring device was so constructed that it, with but slight changes or eliminations of indicator arms, etc., served satisfactorily in all three types of investigations. In Figure 1, it is shown as set up for

* This study has been aided by a grant from Mr. C. F. Samms, President of the General Electric X-ray Corporation, Chicago, Ill.

From the Physiological Laboratory and the Department of Physical Education, University of Chicago.

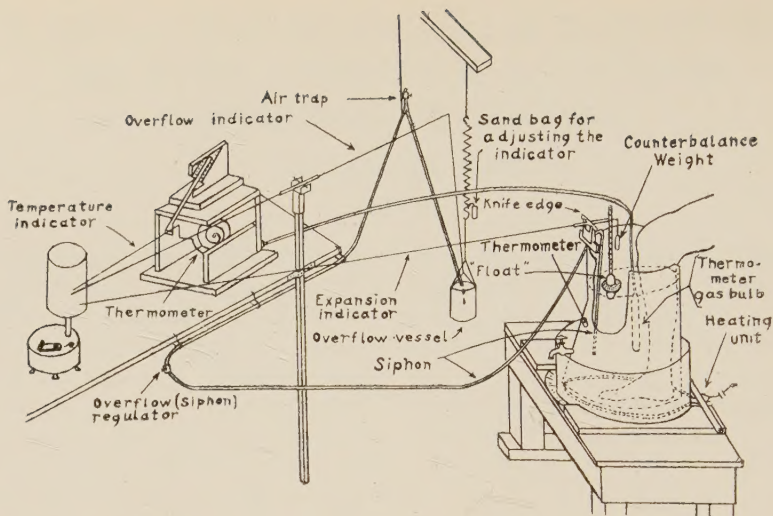


Fig. 1. Shows set up of apparatus for determining volume changes in organs detailed in this report.

experiments with water of a rising temperature — from 3° C. to 47° C. Since this arrangement is the most complex, an explanation of it will be given here; and the set-up for the other experiments may then be made clear by merely mentioning what parts were eliminated.

The cylinder itself was placed inside another vessel, and being soldered on top of small metal blocks resting on the bottom of the larger vessel, a space or air jacket was formed between the walls and bottoms of the two vessels. Between these bottoms was placed an electric heating unit which served to heat the water with which the entire intermediary space was filled during an experiment. The heat from this water was readily transferred through the copper walls of the cylinder itself to the water inside surrounding the foot. In this manner, the water in the cylinder was easily and uniformly raised to, or maintained at, any desired temperature.

To maintain low constant temperatures for the experiments recorded in the third part of this report, we employed another cylinder similar to this, but with the outside vessel almost as high as the inside cylinder. The intervening air space was then filled with ice water, or freezing mixture, if such proved necessary, to maintain a low constant temperature of the water inside the cylinder itself. Two cylinders were also necessary to permit a rapid change from one temperature to another. The water contents of the two

cylinders were brought to the desired temperatures and the foot merely brought out of one and quickly plunged into the other.

The expansion indicator resting on a knife-edge, proved adequately sensitive. Its arms were of proportion of one to thirty-six (1:36), and the writing point on the drum recorded very slight volume change inside the cylinder. The efficiency of this indicator was due largely to the specially constructed float. After considerable unsatisfactory experimentation with several kinds of floats, the one shown in the figure was finally devised and adopted. A rim was placed on the float, and the whole lever so counterbalanced that this rim was "gripped" by the surface film of the water. It proved very accurate. If for any reason the rim was lifted away from the surface film, the equilibrium of the indicator was so greatly disturbed that the whole float was lifted far out of the water.

The thermometer registering temperatures in the cylinder was of a "gas unit" type. The bulb submerged in the water, and the spiral spring connecting with the temperature indicator, as well as the tube between the spiral spring and the bulb, constituted one continuous closed gas chamber. Heating the gas bulb, thus producing higher pressure in the gas chamber, served to straighten the spring, which then moved the temperature indicator on the kymograph. The temperature was checked by a mercury thermometer inserted through an aperture in the cylinder wall.

The over-flow indicator was connected with

TABLE 1—Summary of Measurements of Volume Changes in Foot and Leg Induced by Heat Application of Hot Water, Hot Air, and Diathermy.

Type of Heat	No. of Persons	No. of Tests	Duration of Tests	VOLUME CHANGE IN CC.		
				High	Low	Average
Hot Water (40°-47°)	19	35	5'-20 min.	100 (5.3%)	24 (1.14%)	51.5 (2.76%)
Hot Air (Up to 160° C.)	11	18	30'-80'	85 (5.8%)	- 45 (-2.37%)	42.2 (2.38%)
Diathermy (350-600 m.a.)	12	22	15'-40'	108 (5.26%)	2.0 (.09%)	54.5 (2.88%)

the over-flow vessel which, in turn, was suspended from a spiral spring. In order to secure a sensitive starting position of this indicator, it was first set at some point below the one desired on the kymograph. Sand was then poured into a small container suspended on the spiral spring until the writing point on the kymograph rose to the desired point. The indicator was now so delicately adjusted that the passing of but a few drops of water from the siphon into the over-flow vessel was immediately observed on the drum.

Before submersion of the foot, the cylinder was filled with water to a height which brought the indicator to some convenient mark. In order that this height should not vary from time to time, the indicator point was read against an upright permanent scale in place of the kymograph. To ascertain the the volume of the foot, then, all that seemed necessary was to submerge the limb in the cylinder and then withdraw sufficient fluid to bring the indicator point back to the original mark. This, however, was soon discovered to introduce an error of from 20 to 40 cc. in each measurement. This was due to the adhering of water to the sides of the cylinder as well as to the leg, as the water level was lowered to its original height by the withdrawal. The variation in error was due to two causes: First, the height to which the liquid rose — which in turn depended on the volume of the foot submerged and, second, to the rate of withdrawal of the water. Over the latter we had fair control, but none, of course, over the former. Both of these sources of error were eliminated by withdrawing an amount of fluid slightly greater than the foot before the latter was submerged. Then, as soon as the foot had been placed in the cylinder, a sufficient amount of the withdrawn fluid was returned to place the indicator in its original

position. The remainder of the withdrawn fluid accurately represented the volume of the foot. As the foot was removed from the cylinder, it carried along considerable water, but this error was eliminated from the second measurement by refilling the cylinder to the original height, and then repeating the withdrawal procedure as described above.

Results

Measurements of the influence of the local application of the three types of heat are summarized in Table I. It will be seen that the increase in organ volume (vaso-dilatation, edema?) is nearly the same from each type of heat. If at the end of one test the local vaso-dilatation was maximal, the percentage volume increase is necessarily influenced by the initial state of the blood vessels, and this, in turn, is determined by many factors beyond our control. Where repeated tests were made on the same individual, it was found that, as a rule, the initial volume of the foot and leg was smaller in the morning than in the afternoon.

But the increases in limb volume after heat, as applied in these tests, do not seem to involve maximum vaso-dilatation. Seven tests were made using diathermy after the standard hot water or hot air application, and a further increase in leg volume was obtained (average 20 cc. or 1.03 per cent). Similar results (average 21 cc. or 1.12 per cent increase) were obtained in 20 tests on 10 persons when the hot water application followed one of diathermy or hot air. Some local edema may be involved in these cases. One might conclude, of course, that maximum dilatation would be produced by each form of heat if it were applied longer; or else that each form of heat produces, in part, some special vasomotor irritation and dilatation which cannot be obtained by any other

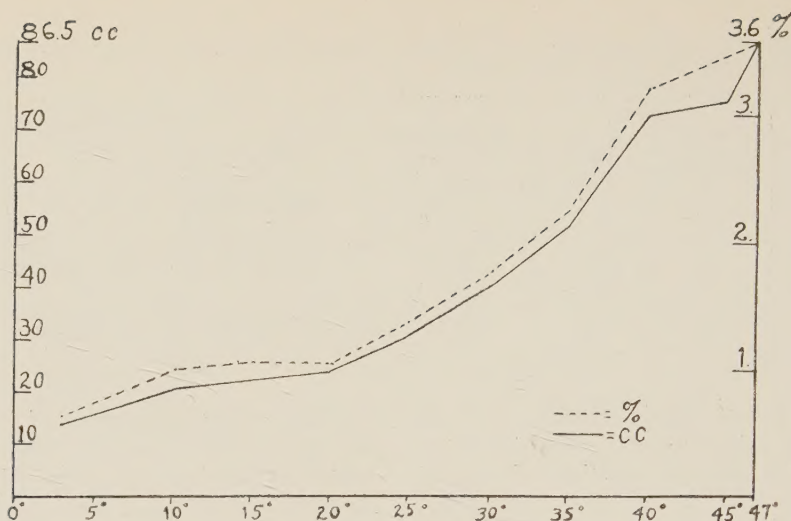


Fig. 2. Volume changes of foot and leg, based on the average of seventy-nine tests on seventy-two subjects.

form of heat, no matter how long it is applied.

The following experiments, with a rising temperature, were undertaken to ascertain whether or not sudden changes in limb volume appear at some particular temperatures. In these experiments it was imperative that the foot be held quiet for a considerable time. The slightest movement of the leg, or even the toes, was recorded on the graph. If the indicator returned to its previous position, such artifacts could be ignored. It is hardly necessary to mention that in these experiments the subjects were not standing, but sitting in a comfortable chair with arm rests.

After the cylinder had been filled to the desired point with water at about 4° C., the foot was quickly submerged and its volume determined by the withdrawing procedure previously described. This operation of correctly inserting the foot and getting the expansion indicator pointing at the desired height on the kymograph drum, need not, after a little practice, require more than five or six seconds. Before the foot was inserted into the cylinder, the expansion indicator, properly attached, was brought in contact with the kymograph drum and the latter revolved so as to enscribe a base-line about one centimeter from the lower edge of the drum. It was to this line the indicator point was returned after the foot was inserted. The temperature, and overflow indicators were adjusted to the same line. (Fig. 1.)

As soon as the foot had been inserted and

the expansion indicator adjusted to the base-line, the current was turned on in the heating unit located below the cylinder. This, as previously indicated, warmed the water in the outer vessel; and the heat was quickly transferred through the cylinder wall to the water surrounding the foot. The rise in temperature inside the cylinder was immediately recorded on the drum by an upward movement of the temperature indicator. The slightest expansion inside the cylinder, due either to volume changes of the leg, or of the water itself, was at once indicated by the expansion indicator by a downward movement on the drum. As soon as the latter movement started, the siphon was opened by means of the over-flow regulator. This released a flow from the cylinder through the siphon to the overflow vessel. By careful manipulation of this regulating device, water was removed from the cylinder as fast as expansion occurred, and quantitatively transferred to the overflow vessel. The latter, being suspended in a spiral spring, descended proportionally to the amount of water transferred to it, and being also attached to the overflow indicator, it produced an upward movement of the latter on the drum.

The graph thus obtained from the overflow indicator registered the combined expansion of the leg and the water. The expansion curve of the water could easily be plotted from tables and then subtracted from the combined overflow curve. In order to eliminate any errors which might possibly originate by a

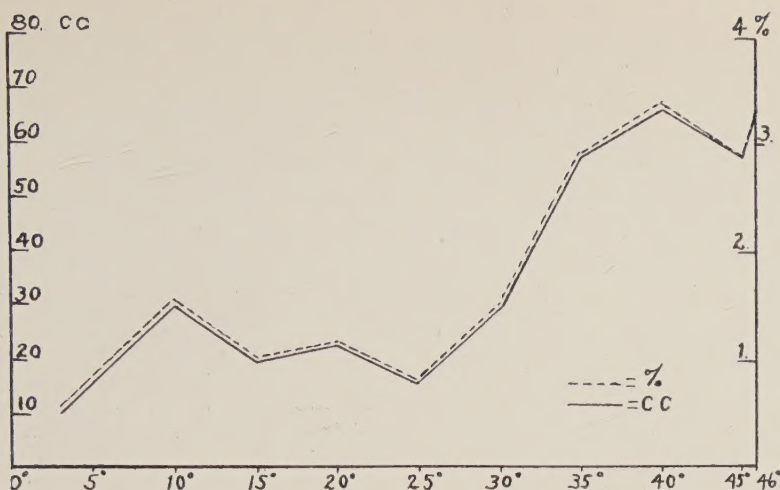


Fig. 3. Volume changes of foot and leg of subject H. P. All applications, in this case, of 10 minutes duration.

slight expansion of the cylinder itself from the heating, we preferred to obtain our own water expansion curve under conditions similar to those under which the experiment itself was performed. To do this, each experiment was always repeated with water only, the water volume used being equal, of course, to that surrounding the limb in the original experiment. The curve obtained from the water alone was then subtracted from the previously obtained combined curve of the foot plus water; and the resultant gave us the true expansion curve of the limb. Eleven of these curves were obtained. The numerical data are presented in Table 2.

Subject 1.—Age 29; weight 120 lbs.; of a quiet and moderately active type, but not athletically active. Later records show a leaning to brooding and moodiness, which developed into definite psychopathic symptoms.

Subject 2.—Age 28; weight 160 lbs.; no regular athletic activity.

Subject 3.—Age 40; weight 170 lbs.; engaged in athletic activity with considerable regularity.

Subject 4.—Age 19; weight 150 lbs.; engaged in athletic activity with considerable regularity.

The expansion averages of 2.8, 3.6, 5.2 and 5.3 per cent provoke speculative conclusions as to the existence of an individual "expansion coefficient." The value of such a coefficient, should its existence be established by more extensive studies, may prove of considerable theoretical and practical interest.

The only unexpected result obtained from the application of water with a rising temperature was the failure to obtain a diminu-

TABLE 2—Limb Volume Expansion on Gradual Increase of External Temperature From 4° C. to 47° C.

Subject	Temperature	Time	Starting			Individual	
			Vol- ume	Increase in cc.	%	Average in cc.	%
1.....	4° C.	46° C.*	21'	1665	42	2.52	47.5
	4° C.	46° C.	30'	1724	53	3.07	
2.....	4° C.	47° C.	28'	2040	63	3.08	
	4° C.	47° C.	23'	2145	62	2.91	72.3
3.....	4° C.	47° C.	23'	1915	92	4.8	
	4° C.	47° C.	22'	2130	91	4.27	
3.....	4° C.	47° C.	25'	2115	124	5.86	
	5° C.	47° C.	25'	2160	109	5.04	111.8
4.....	5° C.	47° C.	30'	2160	123	5.69	
	5° C.	47° C.	25'	1950	100	5.12	103.5
4.....	5° C.	47° C.	25'	1975	107	5.41	

* Subject No. 1 was unable to tolerate a higher temperature than 46° C.

tion of limb volume after the submersion of the foot in cold water. At no time did the volume indicator show a volume decrease. At the low temperature, this increase was slow, to be sure, but constant. As the temperature rose, the rate of increase would vary considerably, not only with the different subjects but also to a marked extent on repeated tests on the same individual. In general, however, these came a rapid increase as the temperature rose above the normal skin temperature, with the most sudden volume change as the temperature rose above 40° C. Another rather uniform observation was a plateau-like effect on the graph as the temperature rose through the 9° C. range. The only explanation here seems to be that there is a temporary inhibition or retardation of the volume increase at this temperature. We shall discuss this phase later.

Thinking that the failure to produce volume decrease (vasoconstriction?) was due chiefly to insufficient time for the cold water to induce the reflex before the temperature rose, experi-

TABLE 3—Summary of Measurement of Leg Volume Changes Resulting from the Application of Water of Constant Temperature, Ranging from about 3° C. to 47° C.

Temperature ° C.	No. of Sub.	No. of Tests	DURATION OF TESTS			VOLUME CHANGE				
			Long	Short	Average	High		Low		Average*
						cc.	%	cc.	%	
45.5-47	7	12	30'	10'	21'	130	(6)	42	(1.5)	86.5 (3.6)
45	6	6	30'	10'	21'	110	(5.7)	11	(.51)	75 (3.48)
40	9	9	27.5'	15'	20.5'	102	(4.51)	20	(.83)	72.5 (3.22)
35	7	7	20'	15'	17.1'	65	(3.3)	36	(1.3)	51.6 (2.28)
30	8	10	20'	10'	15.5'	56	(2.42)	20	(.82)	40.2 (1.78)
25	8	9	17.5'	7.5'	14.4'	52	(2.3)	8	(1.34)	30.9 (1.39)
20	7	9	15'	10'	13.3'	49	(2.15)	-27	(-1.2)	24 (1.06)
15	7	7	15'	10'	13.5'	40	(1.74)	0	(0.0)	22.1 (1.05)
10	4	4	15'	10'	11.2'	30	(1.55)	6	(.27)	20.5 (1.00)
2-4	6	6	10'	10'	10'	30	(1.50)	-15	(-0.685)	13.5 (0.638)

* Represented graphically in Figure 2.

Objections to the averages presented above may be made on the ground that all the graphs do not have the same time factor involved. To obtain such time factor is, of course, highly desirable theoretically, but well-nigh impossible practically. In case of hot water, it requires 20 minutes or more to approach a quantitative maximum result, while in the case of cold water much less time seems to be needed. Furthermore, the pain-factor becomes paramount. Ten minutes is all that an individual can endure at the lower temperatures and maintain the necessary quietness. In order to obtain equal time-factors, one would, therefore, be compelled to cut down the time of the hot water application to that of the cold water — namely, ten minutes, which is

ments were designed to apply at constant temperatures for definite time periods (5, 10, 15 minutes or more). The temperatures chosen ranged from 3° C. up to 47° C. The procedure was as follows: Both the temperature- and overflow-indicators were removed. The temperatures were checked with a thermometer inserted directly into the cylinder through the cylinder wall. The cylinder was filled with water at the desired temperature, the foot inserted and its volume measured by the process previously described.

The limb was kept in the bath as long as the subject could remain quiet. The lower temperature generally produced so much discomfort that ten minutes was all that could be endured at one sitting. At higher temperatures, the time could be extended to 30 minutes, in some cases, before restlessness interfered. No water was withdrawn from the cylinder until the end of the experiment. Consequently, as expansion occurred, the water rose in the cylinder causing the float to rise and the expansion indicator to move downwards on the drum. At the end of the experiment, sufficient water was withdrawn to bring the indicator back to its original starting height. The water volume thus withdrawn corresponded to the increase in the volume of the leg. In the few instances in which constriction occurred, the movement of the in-

not enough for a quantitative reaction in case of hot water. We have, however, run and recorded a few such short applications for comparative purposes. We have also tried to meet the above objections by distributing the unequal time factors fairly equally in each group; and also by graphing results obtained on a ten-minute basis as well as on a longer, or final, basis. (See Figure 4.)

Figures and data submitted in Table 3 are, of course, complete only so far as the end results are concerned. In our original records, every one of these 79 tests is represented graphically on ten different sets of graphs — each set containing all graphs obtained from the experiments at some one temperature, such as 30° C. These graphs give a clear picture of the volume changes as they progress during the entire test period. A brief summation of those graphs are submitted below:

indicator was, of course, in the opposite direction; and to correctly ascertain the extent of the constriction it was only necessary to add water to the cylinder until the indicator again rested at its starting point. The volume of the added water equalled the volume loss through vaso-constriction. Since the water in the cylinder was maintained at a constant temperature, errors due to temperature changes in the water, or in the cylinder itself, were eliminated.

Experiments were run at regular 5 degree intervals, from 10° C. to 45° C. A few experiments were run at 7° C., and several between 2° C. and 4° C. The latter experiments were generally started at about 2° C., but the temperature of the water would rise one or two degrees by the end of ten minutes due to the heat from the leg. A more extensive rise was prevented by a mild freezing mixture placed in the surrounding chamber. Attempts to maintain the temperature at 2° C. or 1° C. for the duration of the experiment required such strong freezing mixture in the outer chamber that ice formed on the inside of the cylinder walls which, of course, at once nullified the experiment. However, since water has its greatest density at 4° C., the rise in temperature from 1° C. to 4° C. certainly did not tend to augment but rather to minimize our results. Above 45° C. several runs were

made at the individual's tolerance. This would vary between 45.5° C. and 47° C., and all the experiments within that range are, therefore, grouped together, in Table 3, and Fig. 2.

In most cases there appears a sudden vaso-motor reaction immediately after submersion of the foot. Generally, the reaction is one of volume increase, and may last from a few seconds to a minute and a half, in a few cases even longer. On the graph it is evidenced by a rapid, in some cases almost perpendicular, rise of the indicator. In the following discussion we have chosen to refer to this phenomenon as the "initial rise."

In group 2° C.-4° C.:—The "initial rise" was small, about 5 cc. Subsequent rate of expansion uniform throughout the test except in case of subject K. P. whose expansion was maximal in about 1 minute (about 12 cc.) after which the graph assumes a form of a wavy plateau, slowly descending until it again reaches the base line after 6 minutes. At the end of 10 minutes there is a volume loss of 15 cc.

In group 10° C.:—The "initial rise" was very small; and subsequent rate of expansion uniform throughout the entire test period, except in case of subject K. P. His initial rise lasted about 2 minutes (volume increase about 23 cc.) after which no further change was experienced during the 10 minute period.

In group 15° C.:—The "initial rise" is even less evidenced than in the previous group. Subsequent rate of expansion uniform throughout the test period except in cases K. P. and V. S. Both of these ran uniform for 6 minutes (gain about 18 cc.). In case of K. P. the expansion then more than doubled during the next 2 minutes, after which no further change was indicated; in case of V. S. a volume decrease set in, and at the end of 10 minutes the leg had returned to its original volume.

In group 20° C.:—The "initial rise" is sharp and distinct in all but one case. Volume change about 12 cc. Subsequent rate of expansion uniform throughout except in case of K. P. After 4 minutes (gain about 30 cc.) volume decrease set in; at the end of 8 minutes, the leg had returned to its original volume, and at the end of the test (15 minutes) there was a volume loss of 27 cc.

In group 25° C.:—The "initial rise" is somewhat smaller than in the previous group, about 8 cc. Subsequent rate of expansion less uniform than in the previous groups with subject K. P. again showing the greatest irregularity. The graph rises very irregularly for 6 minutes, then drops rapidly during the next minute; rises rapidly during the next 6 minutes, only to drop again during the rest of the experiment. Final gain: 26 cc.

In group 30° C.:—The "initial rise" is greater than at any lower temperature; gain about 18 cc. Three individuals, J. H., P. T. and K. P., show a distinct variation from the group. The graph of the first mentioned rises above the rest in the form of an arc of a circle; the second, P. T., remains below the rest in an almost straight line showing no "initial rise;" the last, K. P., shows a

small "initial rise," drops again to the base line within 2 minutes, and finally rises again until the end of the test (15 minutes.) The subject K. P. was run twice at this temperature as a check. This second graph is very similar to the first one in all its irregularities except one; it does not drop back to the base line during the first 2 minutes as did the former; and as a consequence the entire second graph continues considerably above the first, showing a greater gain at the end of the 15 minute test. The gain was 50 cc. while the first run gave a gain of 34 cc.

In group 35° C.:—The "initial rise" continues to increase; gain about 25 cc. The group shows no noteworthy individual variation except, perhaps, in one case, that of K. P. In this group, this subject does not vary exceptionally from the rest, but it is of interest to note that the graph shows a distinct temporary drop after about 3 minutes time, which is a perfect check on a similar irregularity shown in the two graphs from the group at 30° C.

In group 40° C.:—The "initial rise" amounts to about 35 cc. Three graphs show a distinct variation from the group: Subjects V. S., R. T. and P. T. The first shows a decrease in the rate of expansion at the end of one minute; in less than another minute, however, there is a rapid rise lasting about 6 minutes; the next 3 minutes show no change; then, an almost perpendicular rise during one minute, and finally a plateau — no change — during the next 8 minutes. R. T. gave no "initial rise," the graph being an almost straight line during the entire 25 minutes of the test. V. S. gave an "initial rise," but the rate slowed up within one minute; at the end of five minutes a drop began lasting for five minutes, then a perpendicular rise lasting but a fraction of a minute; next a slow rise for one minute; then a drop for 2 minutes; and finally a perpendicular rise at the end of the test. In this group, subject K. P. showed no marked individual variation.

In group 45° C.:—The "initial rise" appears somewhat smaller than in the previous group; gain about 25 cc. Two graphs show noteworthy variations: Subjects V. S. and K. P. V. S. gave no "initial rise"—the graph follows the base line for almost one minute; there is then a fairly rapid rise during 6 minutes; no change for about 2 minutes; then a drop for about 3 minutes; and finally no change during the last 3 minutes. K. P. again shows a sharp temporary inhibition of the rate of expansion. The graph gives a slightly descending plateau at the end of 5 minutes. The effect is brief, however, lasting but one minute.

In group 45.5° C.-47° C.:—The "initial rise" is the greatest of any group: gain about 40 cc. Subsequent rate of gain also rapid but uniform for the group, except subject K. P. who was run three times. All three graphs were widely different. One exhibits some of the irregularities mentioned in the group of 30° C.; the second graph runs true to the general character of the group; and the third rises very rapidly, showing a gain of 80 cc. in 10 minutes.

Since, so far as we know, no normal expansion curve has ever been determined, nothing can be said at present regarding the mean-

TABLE 4—Volume Changes in the foot when Surrounded by Water at the Following Temperatures.

Subject	Temperature	Time	CC. Volume Increase	% Foot and Leg Volume
W. B.	2-4 C.	20'	25)	1.26)
"	"	10' } 13.64'	18) 24.3	.88) 0.121
"	"	10'	30)	1.50)
"	9 C.	15'	30)	1.47)
"	"	10' } 12.5'	20) 25	.96) 1.21
"	15 C.	15'	37)	1.85)
"	"	15' } 15'	13) 21.6	.65) 1.08
"	"	15'	15)	.74)
"	30 C.	25'	60)	2.96)
"	"	15' } 18.3'	28) 46	1.34) 2.23
"	"	15'	50)	2.41)
"	45 C.	20' }	55)	2.96)
"	"	7.5' }	68)	2.32)
"	"	30' } 21.8'	85) 74	4.06) 3.38
"	"	30' }	88)	4.20)
S. B.	2-4 C.	15' }	34)	1.66)
"	"	7.5' }	21)	.97)
"	"	10' } 10.6'	-22) 13.75	-1.05) 0.67
"	"	10'	22)	1.10)
"	7 C.	10'	40)	1.85)
"	"	15' } 11.6'	-6) 21.3	-.28) 0.99
"	"	10'	30)	1.40)
"	25 C.	15'	35)	1.63)
"	"	15' } 15'	46) 34.33	2.10) 1.59
"	"	15'	22)	1.06)
"	35 C.	18'	28)	1.38)
"	"	15' } 16.5'	50) 39	2.30) 1.84
"	40 C.	25'	128)	6.18)
"	"	20' } 22.5'	88) 108	4.14) 5.16
K. P.	20 C.	15'	36)	1.60)
"	"	15' } 15'	-27) 13	-1.24) 0.58
"	"	15'	30)	1.38)
"	30 C.	15)	34)	1.50)
"	"	15' } 15'	50) 42	2.10) 1.8
"	35 C.	15'	68)	3.06)
"	"	20' } 17.5'	50) 59	2.16) 2.61

ing of the curves as obtained. Neither can we give any reasons for the variations shown by subjects V. S. and K. P.

Having obtained such varying vasomotor reactions — both qualitative and quantitative — from our constant temperature experiments when applied to different individuals, it seemed desirable to determine, if possible, the constancy of these reactions in the same individual. Accordingly, two to four constant temperature experiments were performed on each of several individuals. Results obtained from three of the individuals are presented in Table 4. The greatest variation by one individ-

ual at the same temperature is by subject K. P. at 20° C. Duration of tests was the same, yet there was a gain of 1.6 per cent in one test, and a loss of 1.24 per cent in the other. Although subject K. P. was rather erratic in his reactions in all his tests, and as a consequence cannot be considered as typical or average, considerable individual variation can also be observed from the other two individ-

uals. It also seems desirable to submit data demonstrating the consecutive reactions of the individual over the entire experimental temperature range at five degree intervals. Such

data, involving four individuals, are presented in the following Table 5. The figures, of

TABLE 6 — Changes (Increase) in Foot Volume When Surrounded by Water at the Limits of Skin Tolerance *

TABLE 5 — Volume Changes in Foot When Surrounded by Water at the Following Temperatures

Subject	Temp.	Time	Volume in-crease in cc.	Volume in-%
W. B.	2° C.-4° C.	10'	30	1.50
"	"	10	25'	1.14
"	"	17	15'	1.85
"	"	20	15'	1.37
"	"	25	15'	1.87
"	"	30	28'	2.90
"	"	35	15'	2.43
"	"	40	25'	4.05
"	"	45	30'	4.06
"	"	46	30'	4.20
K. P.	2° C.-4° C.	10'	-15	-.69
"	"	10	10'	1.05
"	"	15	15'	1.74
"	"	20	15'	1.61
"	"	25	15'	1.13
"	"	30	15'	1.50
"	"	35	20'	2.16
"	"	40	15'	3.05
"	"	45	25'	4.81
"	"	46	25'	4.30
S. B.	2° C.-4° C.	10'	22	1.10
"	"	7	10'	1.40
"	"	15	15'	.96
"	"	20	15'	1.50
"	"	25	15'	2.10
"	"	30	15'	1.60
"	"	35	15'	2.30
"	"	40	20'	4.10
"	"	45	30'	5.70
"	"	46	30'	6.00
H. P.	2° C.-4° C.	10'	10	.534
"	"	10	10'	1.55
"	"	15	15'	1.35
"	"	20	10'	1.17
"	"	25	15'	.82
"	"	30	20'	1.95
"	"	35	20'	3.3
"	"	40	25'	4.1
"	"	45	10'	5.8
"	"	46	30'	5.54

Individual	W.M.	W.B.	K.P.	H.P.	S.B.	R.T.
47° C.	4.34	4.2	4.30	5.54	6.00	2.40
2°-4° C.	0.70	1.5	-0.69	0.53	1.10	0.67
Difference or range	3.64	2.7	4.99	5.01	4.90	1.73

muscular and vaso-motor; threshold of either central or axon-reflexes; previous temperature acclimatization of the individual; vascular stasis affecting the production and accumulation of metabolites; skin sensory acuity; and pathological condition. It is true that subject R. T., exhibiting the lowest range, was least active physically; but it cannot be said that subject H. P., with the greatest range, was most active.

In Figure 4 the volume changes in cubic centimeters are graphed on a ten-minute basis as well as on final volume. The perpendicular lines indicate the total final volume change, while the distance from the base line to the short horizontal line intercepting each perpendicular, represents the volume changes induced during the first ten minutes. In some cases it will be noted that the perpendicular does not extend as far as the horizontal line. This merely signifies that there is a diminution of volume after the ten-minute period. In other words, the short horizontal line still indicates the position to which the perpendicular would have extended had the experiment been stopped at the end of ten minutes.

When the leg is subjected to alternate exposure to temperatures of 46° C. and 4° C. or slightly higher, for periods of five to ten minutes, there is considerable divergence in reaction from a single individual on different days, as shown in Figure 5. The leg expansion induced by an eight-minute submersion in water at 46° C. may be completely reduced by a submersion in water at 3° for five minutes. One would be prone to anticipate such reaction, at least qualitatively; but this particular experiment was the only one which exhibited such reaction quantitatively, while in about one-half of all the experiments such a reaction was not induced even qualitatively. In subject W. M., experiment B, the cold water actually augmented the expansion induced by the previously applied hot water. It required about 3.5 minutes for the cold water

course, represent only the end-results, and do not indicate the courses or fluctuations in the volume changes during the experiment. In case of each individual, the difference in leg volume at the lowest temperature (4° C.) and at the highest (46° C.) may be considered the individual range. Such data are given in Table 6.

From this data we observe that the individual "ranges" vary from 1.73 to 5.01 per cent. What physiological factors may underlie such a marked variation in "ranges" is, at present, largely speculative. No doubt some or all of the following may be influential: Tonus, both

* All figures represent volume change in per cent.

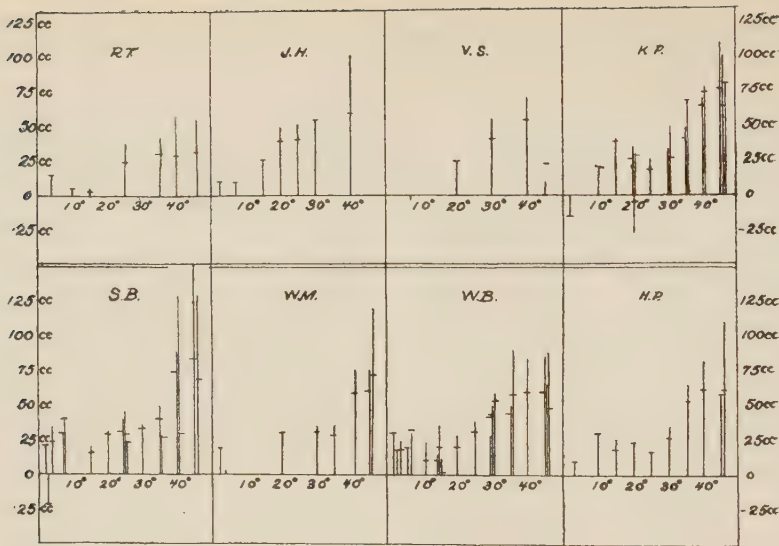


Fig. 4. Volume changes in cc. of foot and leg when surrounded by water at the temperatures indicated. The short horizontal line indicates the volume changes effected by a ten minute exposure.

to merely inhibit the progressive expansion. As the cold water was applied the second time — after the second heat application — the inhibitory effect was initiated in less than one minute, but the cold induced no constriction. As the cold water was applied for the third time — after the third heat application — the inhibitory effect was not only almost instantaneous, but it was followed by a distinct constriction.

Discussion

As previously stated, the effects of diathermy upon the motility of joints, namely, a stiffening effect, left with us the impression that the vaso-dilatory effect of diathermy was less than that of hot water or hot air. These quantitative measurements, however, show that the vasomotor (volume) effects of the three methods of heating are practically the same. The observed rigidity after diathermy may be confined to action on the striated musculature. That some relaxation of the blood vessels is evidenced after diathermy by increased temperature and active hyperemia has been noted by Friedman,⁽⁵⁾ ourselves and others.

Suggestions by Bazett⁽⁸⁾ lead us to make the following comparisons: Hot air, because of its poorer heat capacity and conduction power, can be tolerated by the skin at a much higher temperature than can that of water. We have in some instances applied dry air as hot as 150° C., while

the limit of hot water is about 47° C. Because of its greater heating efficiency water raises the treated part to the maximum point at a much faster rate than does hot air. Since the normal skin temperature is well below the blood temperature, the former is rapidly raised to the blood temperature through the combined effect of the water and blood. As soon as the skin and the underlying tissues attain a temperature above that of blood, the latter becomes a cooling system — and the rate of the local temperature increase is retarded. Ultimately, however, the skin and the subcutaneous tissues assume a constant temperature somewhere between that of the blood and of the water, a further increase being prevented by the cooling influence of the blood. This rise in temperature, however, produces an increased metabolism which in turn raises the tissue temperature still higher, and might, under certain conditions, raise it above that of the surrounding water. The role of the latter is then changed from a heating medium to one of cooling, and now, instead of further stimulating the metabolic processes, it actually serves to retard them.

In case of the hot air, the rise in temperature of the part treated is very much slower, to be sure, but the skin temperature as well as the locally augmented metabolic processes are not ultimately inhibited by the

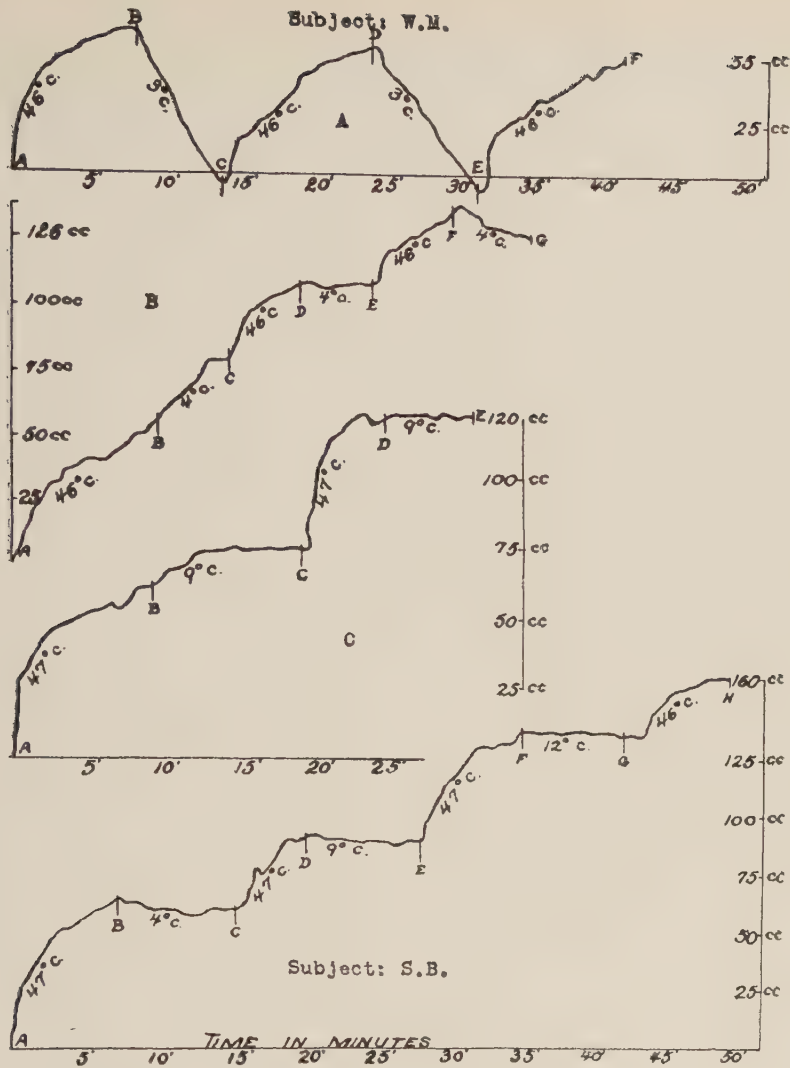


Fig. 5. Graphs of volume changes in foot and leg on alternate exposure to water at the temperatures, and time, indicated. Three experiments on subject W. M. and one on S. B.

hot air, as is the case with hot water. It may be reasoned that the comparatively small amount of heat conveyed to the part by the hot air is carried away equally fast by the blood, and that the local tissue temperature, in consequence, does not assume any higher temperature than it would with hot water. This probably occurs when the circulation is normal, but when congestion is present, the local pyrexia and consequent augmentation of metabolism is probably much greater. Some such effect is actually indicated by the much greater influence on stiffened joints by the hot air application than by either hot water or diathermy. It also conforms to the observations by

Wide⁽²⁰⁾ that a volume increase (of the arm) induced by hot air arises more slowly, but persists for a longer time, than does one induced by hot water.

From the application of water below the skin temperature a vaso-constriction or volume-decrease has been expected. Such an expectation was based primarily on the prevailing opinion and such common practices as applying cold to prevent or reduce swellings. It was more firmly established, of course, by the works of Mosso,⁽¹³⁾ and Amitin,⁽¹⁾ both of whom reported a diminution of volume from the application of water with a temperature below that of the normal skin. The effects obtained by

them were wholly relative, however, as evidenced by the fact that if water at 40 degrees C. was applied to the normal skin with a temperature of about 34° C., an increase in volume occurred; but if it was applied to a skin whose temperature had previously been raised to some point above 40° C. a decrease of volume occurred. Similarly, water above or below the normal skin temperature would, when applied to the normal skin, always produce an expansion when warmer, and a constriction when colder, than the skin. Only one exception is recorded by Mosso: In one case he noted an increase in volume as the temperature of the water was lowered below 10° C. This was a temporary increase only, however, and constriction again set in as the temperature descended below 8° C. This temporary volume increase was obtained by Mosso with a bath of descending temperature, and it has been verified by several of our own experiments in which we used baths with rising, as well as constant, temperatures. The graphs (Figs. 2 and 3) show not only the abrupt volume increase about 9° C., but also the wholly unexpected result of volume increases at all temperatures down to and including 3° C.

When applying water with a *rising* temperature, it might be reasoned that there was insufficient time for the cold water to produce a measurable constriction of the limb before a sensation of warmth would counteract the effect of the cold on the vasomotor mechanism. The time-period between the submersion of the limb and the first sensation of warmth was well above 30 seconds, however, and consequently of sufficient length for the manifestation of vasomotor reflexes and volume changes likely to be caused by the sudden submersion of the limb in the cold water. According to Nothnagel⁽¹⁴⁾ temperature differences of 0.6° C. may be recognized on the leg, and 0.5° C. on the instep of the foot. It is possible that this would be reduced to an even smaller fraction of a degree when such a large skin area is involved as in the present experiment, because the intensity of sensations of warmth and cold are controlled by the relative number of hot- and cold-spots involved.⁽¹⁹⁾ But the acuity of 0.5° C. as given above,

may not be true at the low temperature used by us. These observations by Nothnagel substantiate our own as to the sufficiency of time for the cold water to produce volume changes (constriction) before the water had been heated enough to give a sensation of warmth, as it would require not less than 20 second to raise the amount of water used through 0.5° C. Even though one were to apply the deduction that skin stimulation does not have to be recognized in consciousness in order to produce vasomotor response,^(9, 17, 18) and assume that such responses may actually occur before perception of warmth, it does not seem logical to us to reduce such unconscious reaction time, under these conditions, to fractions of a second. That is, the time required to initiate measureable volume-change does not, from our experiences, exceed one or two seconds as a rule; and the amount of heat imparted by the heating coils to the water during that short period would be too small to counteract and overcome the influence of the cold water.

The total absence of any volume decrease of the limb at these lower temperatures, therefore, forces the conclusion that cold water does not produce such a change. This is further substantiated by the results obtained in our experiments with constant temperature baths, in which the influence from a rise in temperature is wholly absent.

With but few exceptions, all temperatures from 3° C. to skin tolerance—usually about 46.5° C.—produce an expansion of the leg when applied locally. In general, the expansion is smallest at the lowest temperature. Two exceptions are present in most cases: A temporary amplification of the expansion in the region close to 9° C., and a diminished rate of expansion above 45° C. Mosso⁽¹³⁾ and Goldschmidt and Light,⁽⁷⁾ in two out of three experiments, noted a slight enlargement of the hand exposed to cold water. Hewlett⁽⁸⁾ observed a marked vascular dilatation on the exposure of a patient's arm to moderately cold water. However, Hewlett refers to it as "an unusual, if not, a pathological phenomenon." None of these investigators present their data in quantitative terms, i.e., in per cent, so we are unable to compare our results with theirs except qualitatively.

Practically all of the literature relating to the vasomotor effects of local applications of heat and cold, confines itself chiefly to biochemical and minute vascular phenomena and not to gross volume changes. As to the local vascular effect of heat there appears to be uniformity of results of all investigators; Warmth produces a vascular dilatation recognized through an induced surface redness, the intensity of which is increased with the temperature; all blood vessels, large and small, are enlarged, permitting a more rapid flow of the blood through the part.⁽¹⁰⁾ The larger vessels are affected chiefly through spinal reflexes or axon reflexes, and the minute vessels through a direct stimulation, or by metabolites. According to Lewis and Grant,⁽¹¹⁾ and Lewis,⁽¹²⁾ the smaller vessels are "independent both of the central nervous system and of local reflexes." That the color-changes of the skin depends chiefly on the superficial network of minute vessels, especially the venous plexus, and not upon the terminal arterioles and capillaries is asserted by Lewis,⁽¹²⁾ Carrier,⁽⁴⁾ Wetzel and Zetterman,⁽¹⁰⁾ and others.

As to the vascular effect of cold, a more varied opinion seems to prevail. The works of Amitin⁽¹⁾ and Mosso,⁽¹³⁾ in 1897 and 1889, seem to have established the prevailing view that local application of cold produces vasoconstriction and volume decrease. It is true, as previously stated, that Mosso observed a superficial vaso-dilatation and increase in volume at temperatures below 10° C., but that was only in one isolated case. According to Goldschmidt and Light,⁽⁷⁾ on exposure to cold, the skin develops hyperemia, not cyanosis. This conforms to our results. These authors also state that the hyperemia from cold does not begin to appear until the temperature of the water is lowered to 20° C. or below. Cyanosis, when present, always appears at about 20° C. or above. This, again, is in accord with our observations. According to these authors, the blue color of the skin caused by exposure to cold takes place "only at temperatures which produce vasoconstriction and decreased blood flow through the part, but which allow the continuance of oxidative processes in the tissues and an adequate dissociation of oxyhemoglobin." If by "vasoconstriction"

they mean a volume-decrease, our results indicate the opposite. Also, blueness of the skin does not necessarily indicate a general vasoconstriction. Such a color may actually indicate a dilatation of the superficial vessels and an over-filling with slow moving venous blood. In fact, this is the reaction which one is forced to assume in order to explain the constantly occurring limb expansion under those conditions. If the collecting venules and veins contract first on exposure to cold, the superficial network of minute vessels may be expanded by the increased pressure.⁽⁷⁾ The assumption that the collecting venules contract first is made on the basis that they are chilled first, as the blood enters them after having been cooled in the skin. If the tissue temperature is high enough to permit oxidative processes to go on, the net result would be local cyanosis and blue color. But this gorging of the superficial network with blood would also produce volume increase in the limb as a whole. This may, in part, furnish an explanation to the paradoxical results of vasoconstriction and volume increase. For the lower temperatures, we shall see that other factors are involved.

As the temperature of the water is lowered below 20° C., the skin color becomes more and more red, and the leg expansion becomes less and less. Just below 10° C. the leg expansion becomes in some cases proportionately greater, only to again diminish as the temperature descends below 7° C. The increased local redness is fully explained by Goldschmidt and Light⁽⁷⁾ by the local decrease of oxidative processes. Such a condition would leave arterial blood in the superficial network regardless of how slowly the blood circulated. The expansion of the leg upon exposure to the cold water we have already tried to explain, in part, by a primary constriction of the veins and venules with a consequent gorging⁽⁷⁾ of the more proximally located minute vessels. From this, one is likely to deduce that the expansion should increase with the lowering of the temperature, because such lowering would tend to intensify the venous constriction as well as the subsequent gorging effect on the proximal vessels. As previously stated, however, the expansion of the leg lessens as the temperature is lowered.

We believe the factors involved to be as follows: As the venous vessels are constricted by the cooled blood, the circulation is retarded proportionally. The blood now is exposed to a longer cooling process which in turn produces further constriction of the venous vessels, and again, further cooling of the blood. In time, when the circulation is sufficiently retarded, the cooling process begins to affect the arterial vessels as well. As long, however, as the venous constriction is not complete, the arterial vessels are still warmed by the circulating blood, and the constriction of these vessels is retarded. That is, as the temperature is lowered, the vasoconstriction on both the venous and arterial sides is intensified, but the arterial constriction always lags behind the venous. Since the arterial vessels possess a more powerful muscular structure and have more abundant nerve supply⁽²¹⁾ than the venous vessels, it seems logical to deduce that the arterial constriction, as it progresses, is more powerful than the venous. Gradually, then, the former more and more reduces the gorging effect of the latter and the volume of the leg as a whole decreases with the temperature.

The sudden temporary amplification of the leg expansion at 9 degrees C. present in some cases, demands special consideration. Two causes seem plausible: A complete constriction on the venous side would produce a sudden maximum gorging and volume increase; or a sudden paralysis of superficial network, with or without a complete venous constriction, would also produce a similar volume increase. However, as the temperature descends below 8° C. (constriction?) volume decrease again sets in. Once more, two causes seem plausible: first, the cold may begin to exercise a paralyzing influence on the constricted venous vessels; or, second, it may be causing arterial constriction powerful enough to eliminate the venous gorging. Either, or both of these conditions combined, would be sufficient, it seems, to bring about the volume decrease in question.

There is, however, another factor to be considered in relation to the leg expansion by cold, especially about 10° C. and below; namely, that of edema. Barbor and Hamilton⁽⁶⁾ present rather definite proof that the apparent increase in blood cells

produced by the exposure to cold is not an actual increase in total number of cells, but a concentration of blood cells due to the anhydremia caused by the cold. These same authors further state that such a migration of fluid is closely associated with increased capillary permeability, a constant sequel to anoxemia whether produced by cold or other means. The fluid migrates into the surrounding tissue spaces and thus contributes to the expansion of the limb. The existence of such excessive fluid to the parts exposed to cold was demonstrated by these workers. Dogs, after lying on ice for some time, would always show more fluid in the tissues of the side exposed to the cold than on the other side. Sometimes the difference in fluid content would be as great as 16:1 between the cooled and the normal sides. Some of this difference could possibly be due to gravity but no controls were run on this phase. In our own experiments gravity might play a considerable part in the accumulation of the fluid in the foot, especially at the lower temperatures. The hydrostatic pressure in the foot—even with the subject in a sitting position—would favor the accumulation of the fluid in the leg exposed to the cold. This, then, would be an additional factor in the increase in leg volume. It seems, therefore, that the unexpected leg expansion at the low temperature, especially below 10° C., is due, in part at least, to anhydremia and the resulting tissue edema.

In regard to the close relationship inferred above, between anoxemia and anhydremia, we are not convinced that anoxemia is a necessary antecedent to anhydremia. Okuneff⁽¹⁵⁾ showed that blood vessels exposed to warmth also exhibited increased permeability. This suggests that the comparatively great expansion induced by the application of warmth—accepted to be due wholly to vasodilatation—is probably, in part, also due to tissue edema.

That warmth, when applied to the skin, produces by reflex and direct action, relaxation of the blood vessels in the skin is questioned by Lewis.⁽¹²⁾ From one type of experiment he concludes that warmth increases and cold decreases the tonus of the capillaries. Lewis immersed both arms in water at 41° C. to 42° C. until a distinct hyperemia was produced; the

arms were then reimmersed: one in water at 32° C. and the other in water at 20° C., and the time noted for the hyperemia redness to disappear. He found that at 32° C. the redness disappeared after two to three minutes, while five to eight minutes were required at 20° C. The inference is that if cold causes vasoconstriction, the hyperemia should have disappeared quickest at 20° C. Lewis' interpretation of this experiment can not be accepted until limb volume measurements are made under the conditions of the experiment.

The difference in results obtained by us from those of Mosso⁽¹³⁾ and Amitin⁽¹⁾ may be due to the different methods employed. These workers generally placed the arm in water at temperature close to the existing skin temperature, and then gradually increased or decreased the temperature. In decreasing the temperature, for example, there was a constant and continuous irritation or stimulation of the cold spots during the entire cooling process—which in their experiments generally lasted for hours. In our own experiments, lasting from 10 minutes to 30 minutes, the limb was submerged at once into the desired temperature which was then kept constant. Since the temperature sensations are induced chiefly by *changes* in temperature, it would seem plausible that the prolonged cooling process produced a cumulative effect which differs from the effect produced by a sudden immersion into the constant temperature bath.

There are other factors present, however, which when considered make our results similar to those of Mosso and Amitin. It is only necessary to assume that those workers, after placing the arm in water at skin temperature, permitted it to remain there long enough for it to assume the volume change induced by water at that temperature. This change amounts to an increase of about 2 per cent of the original volume. At a lower temperature, such as 20° C., the increase is only about 1 per cent, and at 3° C., it is only 0.64 per cent, of the original volume. From this, one may, as did those early observers, draw the conclusion that cold produces a diminution in volume or vasoconstriction; but it should be noted that although the volume

measured at 3° C. is smaller than the one at skin temperature, the arm is still 0.64 per cent larger than it was before the original immersion at skin temperature. This would verify our own results as well as those of Mosso and Amitin. Lastly, there is the possibility that since these other workers carried out their experiments on the arms and we took our measurements on feet and ankles, that the difference in hydrostatic pressure may be a determining factor in the volume changes obtained.

Conclusion

1. The vasodilator influences, as measured by organ volume, of diathermy, hot water and hot air were found to be about equal. When applied to the foot and ankle, each produced an average increase in volume of approximately 2.5 per cent of the original volume of the limb; and when applied in immediate sequence to each other, there was an increase in volume, in all three cases, very close to 1 per cent of the original volume.

2. Evidence is brought forth which indicates that the stiffening effect of diathermy upon joints is confined chiefly, if not entirely, to the striated musculature.

3. When the foot and ankle are immersed in water at about 4° C. and the water then heated to skin tolerance, usually about 46.5° C., within a 25 minute period, there occurs a volume increase which varies considerably with the individual. In our experiments, the lowest increase was 2.8 per cent, and the largest 5.3 per cent, of the original volume. The results indicate the existence of an individual as well as a normal "expansion coefficient."

4. Water applied locally, at extreme hot temperatures, 45° C. to 47° C. produce an expansion which in general is 50 per cent, or more, complete in five minutes, and 70 per cent, or more, complete in 10 minutes.

5. While the expansion by the hot water is in progress, especially after the first five minutes, it may be retarded, inhibited, or even reversed by the application of cold water—particularly at temperatures below 10° C.

6. If, after such an inhibition by cold

water has been produced, hot water is re-applied, limb expansion is again produced with almost as great initial rate as in the first application of hot water.

7. By alternate application of hot and cold water, in a manner indicated above, a greater final expansion seems to be produced than by a continuous application of hot water alone.

8. Immersion of the foot and ankle in water at any temperature between 3° and 47° C. produces, in general, a volume increase, the increase becoming greater as the temperature is raised. One exception is noted: A marked irregularity occurs in some cases in the expansion at about 9° C. The results indicate a "critical" vasomotor reaction at, or close to, 9° C.

9. The reason our results seem to directly oppose those of earlier investigators (Mosso, and Amitin) is thought to be due to the different methods used, and to the great difference in duration of the experiments, as well as to a difference in hydrostatic pressure, as those investigators measured hands and arms, while we measured feet and ankles.

10. The volume increase induced at the lower temperatures is thought to be due to the combined effects of edema resulting from "cold anhydremia," and an expansion of the minute blood vessels. The latter in turn, being due either to a gorging effect caused by a venous constriction, or to a paralyzing action produced by the cold, or by both.

11. As the temperature of the water is lowered below 20° C., a distinct reddening of the skin occurs, the redness increasing as the temperature is lowered.

12. The conclusion drawn by Lewis⁽¹²⁾ that within moderate temperatures, cold reduces and warmth increases the tonus of the minute blood vessels appears to be erroneous.

The writer wishes to express his appreciation and hearty thanks to Professor A. J. Carlson, department of physiology, for his patient supervision and helpful criticism; to Athletic Director A. A. Stagg for his permission to conduct the experiments in the athletic training quarters; to Dr. J. B. Hoag, department of physics, for advice and counsel; and to his wife for help in compiling the report.

References

1. Amitin, S.: *Zeitschr. f. Biol.* **35**:13, 1897.
2. Benson, Simon: Relative Influence of Diathermy and Other Physical Therapy Measures on Stiffened Joints. *Research Quarterly*, **1**:52, 1930.
3. Bazett, H. C.: Physiological Responses to Heat. *Phys. Rev.*, **7**:531, 1927.
4. Carrier, E. B.: Studies on the Physiology of Capillaries. *A. J. Physiol.*, **61**:528, 1922.
5. Friedman, M. H.: Local Diathermy: Influence on Kidney Secretion and on Intramuscular and Subcutaneous Absorption. *J. A. M. A.*, **92**:1648, 1929.
6. Barbour, H. G., and Hamilton, W. F.: Evidence that Cold Anhydremia is Due to the Loss of Fluid from the Blood Stream. *A. J. Physiol.*, **73**:315, 1925.
7. Goldschmidt, S., and Light, A. B.: The Effect of Local Temperature upon the Peripheral Circulation and Metabolism of Tissues as Revealed by Gaseous Content of Venous Blood. *A. J. Physiol.*, **73**:146, 1925.
8. Hewlett, A. W.: Active Hyperemia Following Local Exposure to Cold. *Arch. Int. Med.*, **11**:507, 1913.
9. Hewlett, A. W., and Van Zwaluwenberg, J. G., and Marshall, Mark: The Effect of Some Hydrotherapeutic Procedures on the Blood Flow in the Arm. *Arch. Int. Med.*, **8**:591, 1911.
10. Kahn, Fritz: "Människan," (Stockholm, Sweden). **21**:270, 1930.
11. Lewis, T., and Grant, Ronald: Observations upon Reactive Hyperemia in Man. *Heart*, **12**:73, 1926.
12. Lewis, T.: The Blood Vessels of the Human Skin and their Responses. London, Shaw & Son, 1927, pages 143, and 149.
13. Mosso, U.: *Arch. Ital. de Biol.*, **22**:346, 1889.
14. Nothnagel, A.: *Handbuch der Physiologie des Menschen*. Wien, Germany, 1905, page 687.
15. Okuneff, N.: Über den Einfluss lokaler thermischer Reize auf die Abwanderung eines intravenos injizierten kolloidalen Farbstoffes aus dem Blute. *Phluger's Arch.*, **204**:261, 1924.
16. Stewart, N. G.: Studies on the Circulation in Man. **3**:33, 1911-12.
17. Stewart, N. G., and Laffer, W. B.: A Study of Vasomotor Reflexes elicited by heat and cold from the regions devoid of temperature sensibility (in an unusual case of posttyphoid neuritis). *Arch. Int. Med.*, **11**:365, 1913.
18. Stewart, N. G., and Walker, G. M.: Vasomotor Reflexes elicited by heat and cold from areas deprived of temperature sensibility by traumatic lesion. *Arch. Int. Med.*, **11**:381, 1913.
19. Wetzel, N. G., and Zetterman, Y.: On Differences in the Vascular Coloration of Various Regions of the Normal Human Skin. *Heart*, **13**:357, 1926.
20. Wide, Anders: *Handbook i Medicinsk och Ortopedisk Gymnastik samt Massage*. Stockholm, Sweden, 1912, page 184.
21. Woollard, H. H.: The Innervation of the Blood Vessels. *Heart*, **13**:319, 1926.

